Behavior of Khassa Chai Earth Dam under Earthquake Excitation

Dr. Mohammed Y. Fattah
Building and Construction Engineering Department, University of Technology/Baghdad
Haider H. Alwash
Building and Construction Engineering Department, University of Technology, Baghdad
Sarah. A. Hadi
Building and Construction Engineering Department, University of Technology, Baghdad
Email:sarah_25688@yahoo.com

Received on:6/5/2015 & Accepted on:17/12/2015

ABSTRAT:

An earth dam is built of suitable available soils obtained from borrow areas or required excavation which are then distributed and compacted in layers using mechanical means. Earth dams can be constructed of one material to be homogeneous or multiple materials to be zoned dams. Zoned dams are usually advised since zoning allows the use of several different types of material in the embankment which may be available from areas of borrow or required excavations.

This paper presents a dynamic analysis on a zoned earth dam subjected to earthquake motion in which pore water pressure, effective stresses and displacements are calculated. The finite element method is used and the computer program Geo-Studio is adopted in the analysis through its sub-programs SEEP/W and QUAKE/W. As a case study Khassa Chai dam is selected, it is located on Khassa Chai river and constructed of zoned embankment, it has a total length of 3.34 km. The selected earthquake for the analysis is El-Centro earthquake with a period of (10 sec) and different amplitudes of acceleration. The time of the analysis is taken as (600 sec.) with a time step (Δt = 0.05 sec.) to investigate the behavior of the soil for a period of time after the earthquake has stopped, a free vibration period is included in the analysis. It was concluded that, the value of pore water pressure generated at the base of the core is greater than that in the upper parts of dam, the horizontal and vertical effective stress continue to decrease during the period of analysis (600 sec) which indicates that the soil continues to weaken during this period, the horizontal displacement increases with depth of the point from the crest and the largest horizontal displacement will be at the base of the dam at time 60 sec and There is attenuation of the acceleration to some degree depending on the amplitude of the input horizontal acceleration.

Keywords: Earth dam, earthquake, finite elements, liquefaction.

INTRODUCTION

Earthfill dams are considered the most common type of dams basically due to their construction materials from required excavations and available locations, natural materials, which require a minimum of construction stages. Using large amounts of required excavation and available materials from borrow areas are economic factors in construction of earth fill dam. In addition, earth fill dams can be constructed on weaker soils than other types of dams and in areas where the ground topography is less suitable to other types of dams. Earth fill dams will probably continue to be more preferable than other types for the purposes of water storage. Despite that the classification of earth fill dams includes a number of types, the development of modern excavating, transportation of materials, and compaction equipment for earth materials has made the use of compacted fill type so economical as to

https://doi.org/10.30684/etj.34.15A.1
2412-0758/University of Technology-Iraq, Baghdad, Iraq

virtually replace the semi-hydraulic- and hydraulic-fill types of earth fill dams constructed by mixing soil with water, then injection of the slurry to the fill where it is stilled, and then allowing the soil to settle out of the water.

Moreover, compacted fill dams reveal more stability against earthquake loading when compared to hydraulic fill dams. Earth fill dams of the compacted fill type can be further classified as "homogeneous" or "zoned including inclined or central impervious core". Zoning is performed to ascertain safety in terms of suitable strength and control of water seepage and core cracking. For many dams, it is possible to design several safe types of zoning. The final selection of the dam zones, therefore, is a subject of design of the cross section which results in an ideal compatibility between economical use of materials from excavation and available materials from borrow areas and safety. As a defense against potential for cracking, the downstream part of the dam should be drained using a horizontal drainage layer accompanied by a vertical or inclined filter drainage layer. A drained downstream shell allows using of materials of lower quality (U.S. Bureau of Reclamation, 2011).

Nsaif (2008) and Fattah and Nsaif (2012) carried out a coupled dynamic analysis on zoned earth dam under the effect of earthquake excitation where both displacements and pore water pressures are estimated. The finite element analysis was adopted and the computer program QUAKE/W was utilized for the task. A parametric study was performed to study the effect of the amplitude of earthquake horizontal acceleration on the dynamic response of the dam. It was concluded that when the input motion maximum horizontal acceleration increases, both the vertical and horizontal displacement increase. In all the studied cases, the effect of the input ground acceleration diminishes at time (60 sec.) from the starting time of earthquake motion. When the maximum horizontal acceleration of the earthquake shock increases from (0.05g) to (0.2g), the horizontal acceleration which is estimated at a node located at the base of the core increases by about (200 %), at the same time the maximum effective stress increases by about (32 %).

Khalil (2012) studied the development of pore water pressure within a thin clay core in an earth dam. The study consisted of two parts; the first part is a parametric study on general thin clay core (without and with the presence of chimney drains), while the second part dealt with a case study of Badush dam. Different levels of operation and times of storage with the possibility of rapid rise of water level were considered for the case study. After that, the effect of an earthquake on development of pore water pressure in this type of dam was studied as a case study. Two dimensional finite element analysis was adopted to simulate pore water pressure development by the Geo-Slope software taking into consideration saturated /unsaturated conditions. The results revealed that the presence of a chimney drain has an effective role in dissipation of the pore water pressure. In the case of Badush dam, three selected sections through the dam were selected for the analysis. High pore water pressure values were observed, in 8 days as a consequence of a rapid rise of water level and it must be taken into account in the design of dams. The results also indicated that the pore water pressure is in the range of (145-175 kPa) across the typical section and approximately between (25-50 kPa) for the two other sections at the time of the end of construction, which makes the height and construction time of the dam the most effective factors affecting pore water pressure development.

Fattah et al. (2015) utilized the finite element method to study flow through the body of an earth fill dam. For this purpose, the computer program Geostudio 2007 was used through its sub-programs SEEP/W and SLOPE/W. The levels of water on the upstream and downstream sides, the boundary conditions of the dam and the properties of materials were input variables and the water flux and pore water pressure were the target results. The Dau Tieng reservoir, which is located in Tay Ninh province in Southern Vietnam, was analyzed as a case study. The condition of rapid drawdown was simulated by means of the staged construction mode. It was concluded that "the factor of safety against sliding of the dam slopes decreases slightly within the short period after the start of rapid draw down of water in the reservoir, then starts to increase. This is caused by dissipation of excess pore water pressure with time which leads to increase the effective stresses in the soil and hence increase its shear strength. The saturated weight of the slope produces the shearing stresses while the shearing resistance is decreased considerably because of the development of the pore water pressures which do not dissipate rapidly. When the stability of a zoned earth dam is examined during rapid draw down under different water levels in the reservoir, the insufficient stability may occur in the upstream slope as soon as the water is lower than the drawdown level of 1/3 of the dam height. It can be explained that the water load has disappeared during rapid drawdown and the hydrodynamic pressure creates the tensile-downward forces, resulting in a decrease of the shear resistance of the upstream slope. Besides, there is no supporting pressure to resist against mobilizing of the upstream slope".

Khassa Chai Dam

Khassa Chai dam is located on Khassa Chai river upstream Kirkuk city. The Khassa Chai river is a tributary of Zaghitun river which is flowing into the existing Al-Adhaim Dam reservoir. The dam site is located near Kuchuk village, 10 km northeast of Kirkuk city as shown in Figure (1). The dam consists of composite section of pervious and impervious materials. The shell of the dam consists of pervious material, and a core of impervious materials.

Embankment zoning provides an adequate impervious zone, transition zones between the core and the shells, seepage control, and stability. The base of the dam is composed of a series of formations, which vary according to the depth from stiff to very stiff brown silty clay with a lot of medium to coarse grained gravel and black traces of organic matter.

The shell consists of sand and gravel, the upstream slope is (1:3vertical: horizontal) while at the downstream is (1:2.5), and the top width is (14 m).

The core is central composed of silty clay with a slope of (1:1) for both upstream and downstream sides, the top width is (13 m) and this width gradually increases until it reaches (128 m) at the base. Chimney drainage is adopted downstream of the core with (2 m) thickness as illustrated in Figure (2) (Center of Engineering Designs and Studies).

Seepage analysis of Khassa Chai dam

Seepage through and under the dam is analyzed using the program SEEP/W. The finite element mesh used for the analysis is shown in Figure (3). The mesh includes higher-order six-node triangular elements. The upstream boundary nodes are designated as head boundaries with total head equals to the water level in the reservoir, and the downstream boundary nodes are designated with total flux equals to zero. The bottom nodes along the foundation are designated as a zero discharge (no flow).

Dynamic analysis of Khassa Chai dam

After the seepage analysis is done, the dam is analyzed by the program QUAKE /W depending on results carried out by the program SEEP/W. The finite element mesh used for the analysis is shown in Figure (4). The mesh includes higher-order six-node triangular elements. In dynamic analysis, the left and right vertical boundary conditions on nodes are assumed to be free to move in the horizontal direction but they are fixed in the vertical direction. The boundary conditions along the horizontal base of the foundation are assumed to be restrained in the vertical directions and free in the horizontal direction.

Linear elastic model is used in the analysis. The damping ratio is assumed to be (0.02).The selected earthquake for the analysis is El-Centro with a period of (10 sec), Figure (5) shows the acceleration–time history for El-Centro earthquake.

The material properties of different zones in the dam body and its foundation are listed in Table (1), some properties were assumed and the others from (Center of Engineering Designs and Studies, 2007).

The Effect of Earthquake on Khassa Chai Dam

Only the horizontal component of motion is considered in the analysis by studying its effect on the behavior of the dam.

The peak acceleration of the input horizontal earthquake record is modified to three values; 0.05 g, 0.1 g and 0.2 g. So, that the earthquake record is scaled for each case.

For the previous case, three water levels are taken as:

- Minimum water level (26 m).
- Normal water level (40 m).
- Maximum water level (55 m).

The results are shown in the form of figures which include: pore pressure, vertical and horizontal effective stress, x-displacement and x-acceleration -time history for different nodes selected to represent different locations through the dam such as shell, core and foundation., displacements along two sections through the dam body at time (60 sec), liquefaction zones and pore water pressure contours at time (600 sec.). These results will be discussed as follows:

Khassa chai dam with its actual design (with filters) at maximum water level

As the input acceleration increases from (0.05 g) to (0.2 g), the value of pore water pressure at node (3) is the same and it is about (310 kPa), liquefaction starts at time (510 sec) when the input acceleration is (0.05 g and 0.1g), and at (512 sec) when the input acceleration is (0.2 g)as shown in figures, while the pore water pressure at node (5) is rapidly increased at the early times of the analysis reaching a value of (300 kPa) and the time of initiation of liquefaction decreased as the value of the input acceleration increased., where the time required for soil to liquefy when the input acceleration is (0.05 g) is (264 sec), when the input acceleration is (0.1 g) is (236 sec), and when the input acceleration is (0.2 g) is (184 sec), these results are shown in Figures (6) and (7).

Figure (8) shows the response of node (1), located at the dam crest and the results are also shown in Table (2). It can be concluded that there is attenuation of the acceleration to some degree depending on the amplitude of the input horizontal acceleration. The attenuation ranged between (25-78) %.

It is known that soil deposits, in general, tend to amplify the underlying rock motion to some degree as stated by Das and Ramana (2011). The present results in contrast showed attenuation of wave motion which means that the soils of the dam body represent soft materials.

It can be concluded that as the water level increased from minimum to maximum and as the input acceleration increases from (0.05 g) to (0.2 g), the value of pore water pressure generated at the base of the core is greater than that in the upper parts of dam.

The horizontal and vertical effective stress continue to decrease during the period of analysis (600 sec) which indicates that the soil continue to weaken during this period.

Figure (9) displays the variation of horizontal displacement along sec. at time 60 sec. after the occurrence of earthquake under different amplitudes of the input motion. It can also be noticed that the horizontal displacement increases with depth of the point from the crest and the largest horizontal displacement will be at the base of the dam at time 60 sec.

Liquefaction zone will continue to grow after the earthquake has stopped and during the analysis period until larger than 50% of the upstream shell and part of the core becomes within the liquefaction zone as shown in Figure (10), also it can be noticed that the time of initial liquefaction is affected by the ground acceleration only under the maximum water level as shown in Figure (11).

Figure (12) shows the distribution of contour lines of pore water pressure through the dam and its foundation under different water levels and maximum horizontal acceleration of 0.2 g.

Table (3) summarizes the minimum and maximum values of the deviatoric stress at different water levels. The values reveal that the increase of earthquake magnitude leads to increase the

level of deviatoric stresses at some zones which increases the failure potential by shear or by liquefaction.
Table (4) summarizes the maximum values of pore water pressure and the time of their occurrence under different water levels and ground acceleration of 0.2g. It can be noticed that the pore water increases with time during the period of earthquake and also after the earthquake.

Table (1): Material properties of Khassa Chai dam.

Material	Dynamic elastic modulasE (kN/m^2)	Poisson's ratio (v)	Unit weight (KN/m^3)	Coefficient of permeability k_h(m/s)	Volumetric water content (%)
Shell	19000	0.3	18	$1.25x10^{-5}$	15
Core	30000	0.45	20	$2.25x10^{-10}$	25
Filter	19000	0.3	18	$1.25x10^{-5}$	15
Foundation	15000	0.48	19	$1x10^{-10}$	30
Drain	150000	0.28	23	$1x10^{-2}$	10
Blanket	30000	0.45	20	$2.25x10^{-10}$	25

Table (2): Acceleration response of node (1) under maximum water level with the presence of filters

Acceleration (g)	Maximum X-displacement (m)	Maximum X-acceleration (m/sec^2)	Maximum X-acceleration (g)
0.05	0.0419	0.396	0.04
0.1	0.0529	0.552	0.056
0.2	0.00817	0.913	0.093

Table (3): Values of deviatoric stress through the dam with filters under maximum horizontal acceleration of 0.2 g

Water level	Deviatoric stress (kPa)	
	Minimum	Maximum
Minimum	5.34	673.21
Normal	5.06	701.9
Maximum	3.42	748.16

Table (4): Computed values of maximum pore water pressure through the dam with filters under maximum horizontal acceleration of 0.2 g.

Time (sec)	Maximum pore water pressure (kPa)		
	Minimum W.T.L	Normal W.T.L	Maximum W.T.L
10	771.984	909.415	1055.62
60	774.649	909.486	1055.65
600	838.968	913.029	1058.71

CONCLUSIONS

1. The increase in the input acceleration delays the liquefaction occurrence when the value of acceleration is below (0.2g).
2. The time required for liquefaction to take place in node (5) is less than that required for node (3) which is located near the core base due to high overburden pressure at node (3)
3. There is attenuation of the acceleration to some degree depending on the amplitude of the input horizontal acceleration. The attenuation ranged between (25-78) %.
4. The value of pore water pressure generated at the base of the core is greater than that in the upper parts of dam.
5. The horizontal and vertical effective stress continue to decrease during the period of analysis (600 sec) which indicates that the soil continue to weaken during this period.
6. The horizontal displacement increases with depth of the point from the crest and the largest horizontal displacement will be at the base of the dam at time 60 sec.

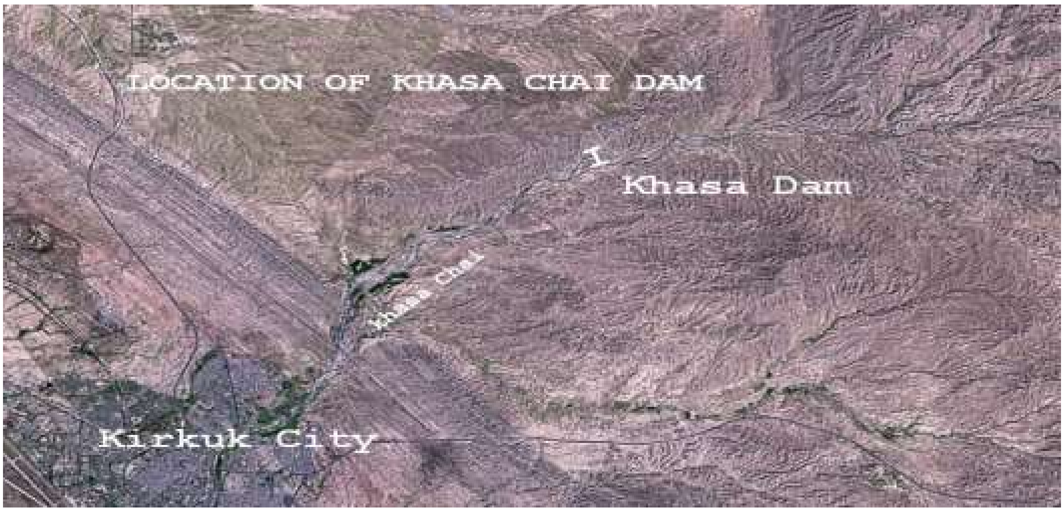


Figure (1) Location of Khassa Chai dam (Center of Engineering Designs and Studies)

Figure (2): Typical cross-section of the dam (Khassa Chai Dam Planning Report, 2007).

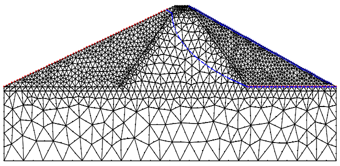


Figure (3): Seepage analysis for the case of minimum water level.

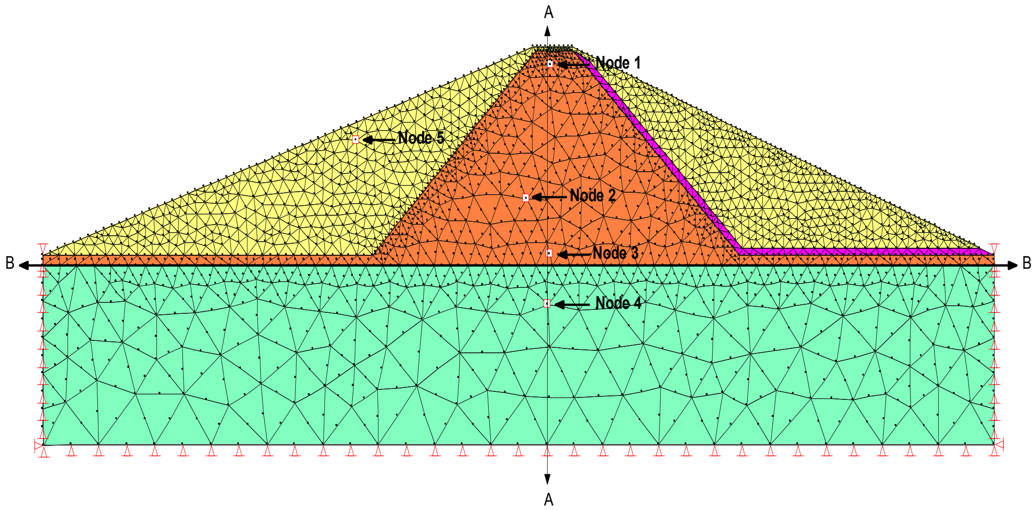


Figure (4): Finite element mesh for dynamic analysis of Khassa Chai dam.

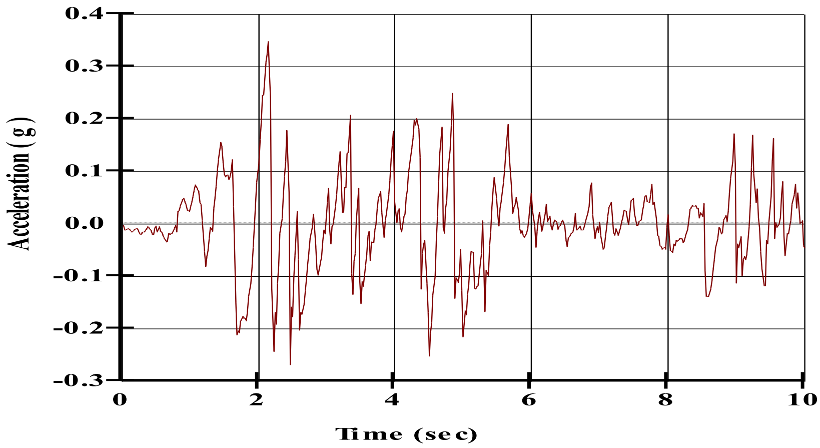
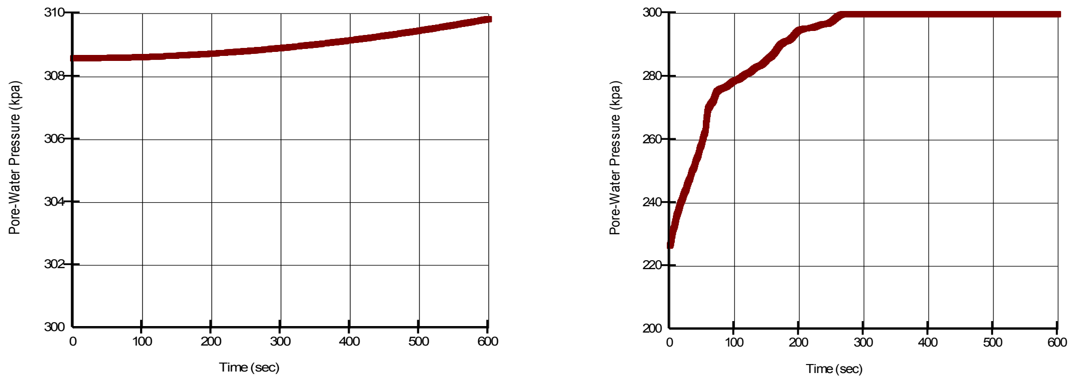
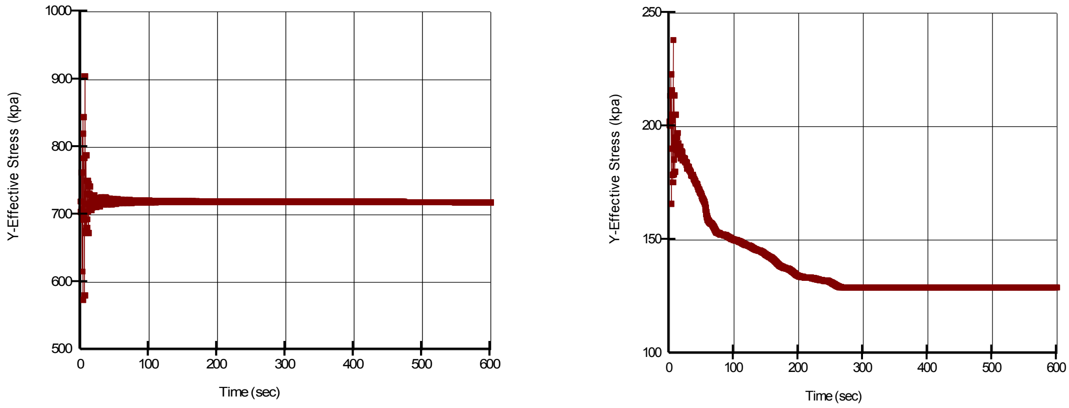


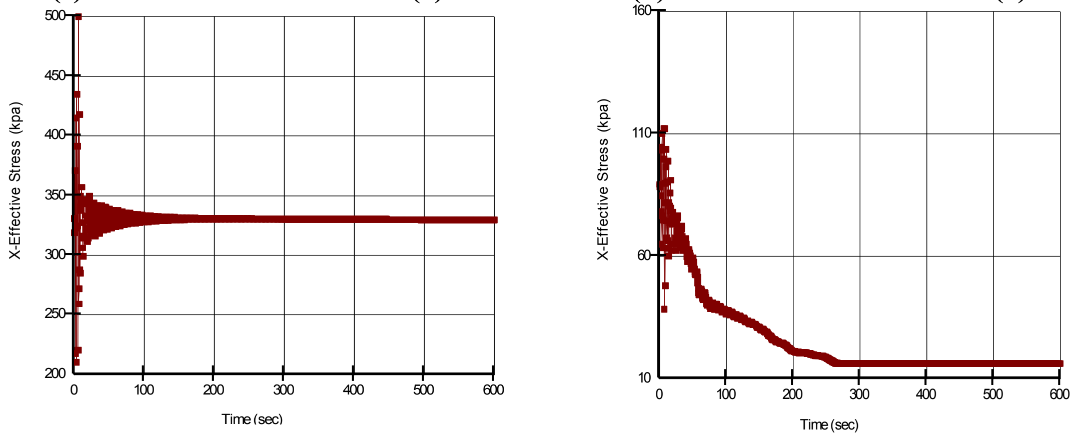
Figure (5): The Acceleration-time history record for El-Centro earthquake, (QUAKE/W, 2004).



(a) Pore water pressure at node (3) (b) Pore water pressure at node (5)

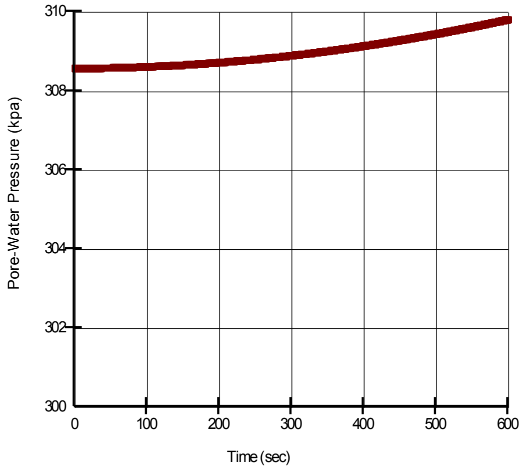


(c) Y-effective stress at node (3) (d) Y-effective stress at node (5)

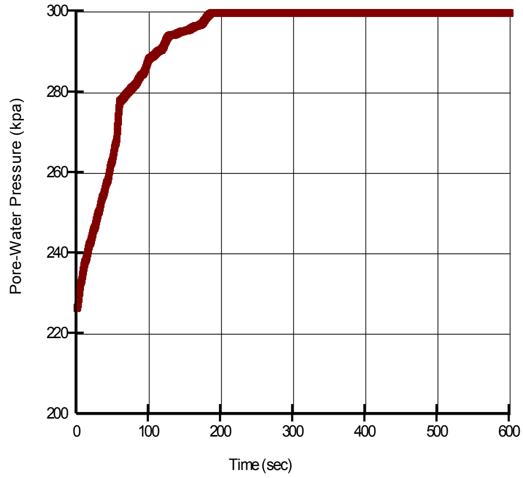


(e) X-effective stress at node (3) (f) X-effective stress at node (5)

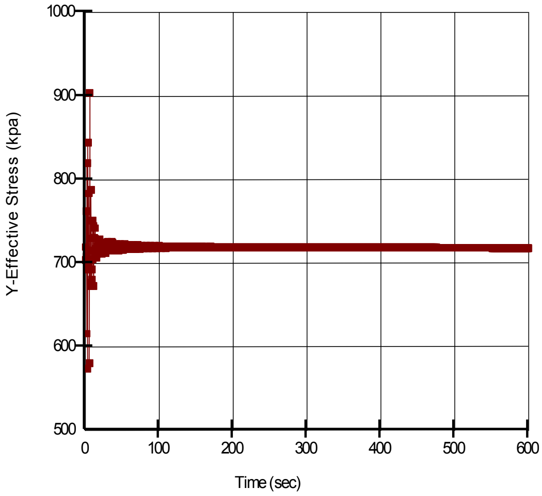
Figure (6) Earthquake response of nodes (3) and (5) under a maximum horizontal acceleration of 0.05 g



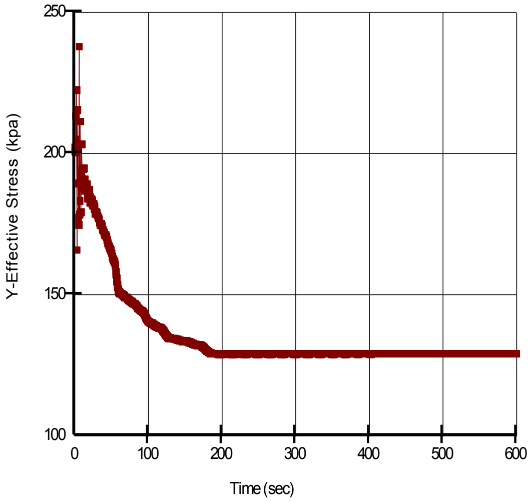
(a)Pore water pressure at node (3)



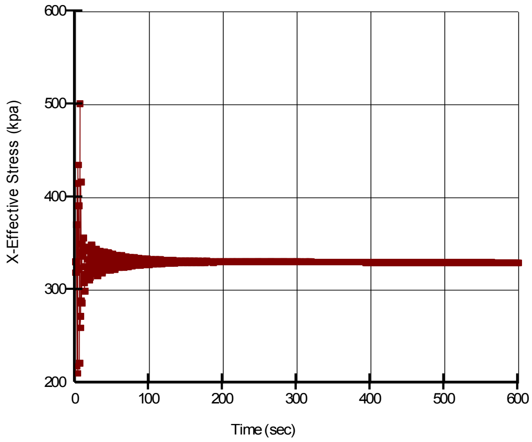
(b) Pore water pressure at node (5)



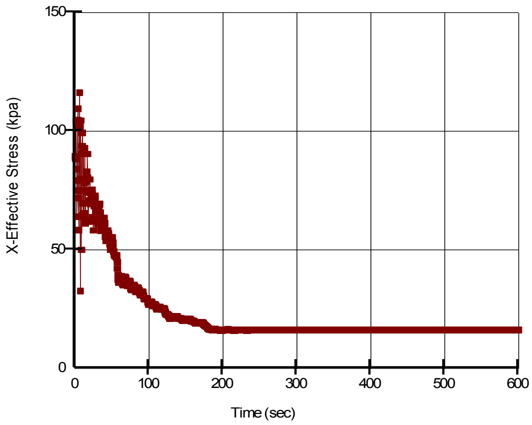
(c) Y-effective stress at node (3)



(d) Y-effective stress at node (5)

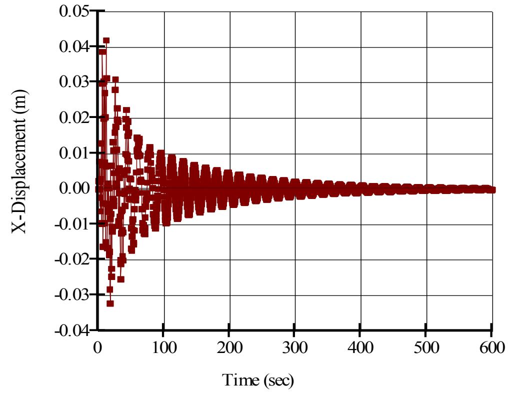


(e) X-effective stress at node (3)

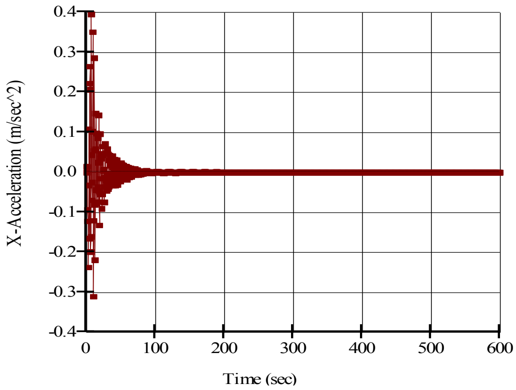


(f) X-effective stress at node (5)

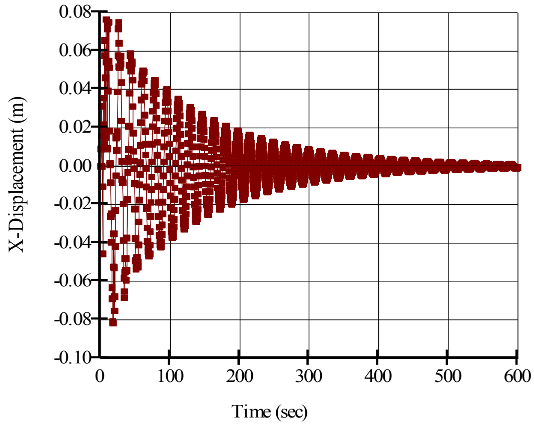
Figure (7) Earthquake response of nodes (3) and (5) under a maximum horizontal acceleration of 0.2 g



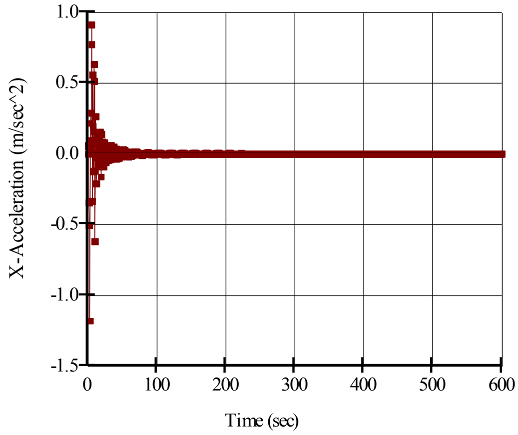
(a) horizontal displacement at 0.05g.



(b) horizontal acceleration at 0.05g.

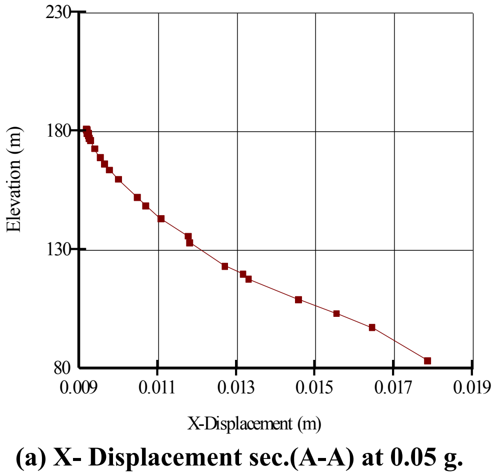


(c) horizontal displacement at 0.2g

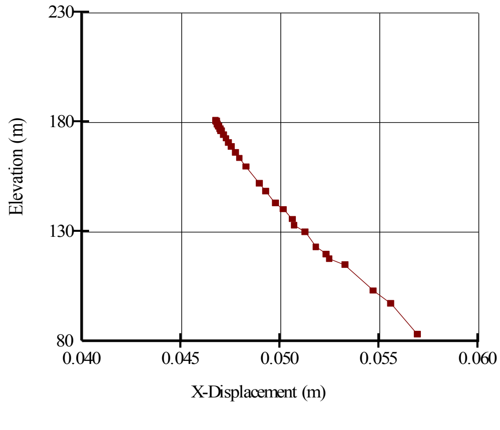


(d) horizontal acceleration at 0.2 g

Figure (8) Earthquake response of node (1) at maximum water level

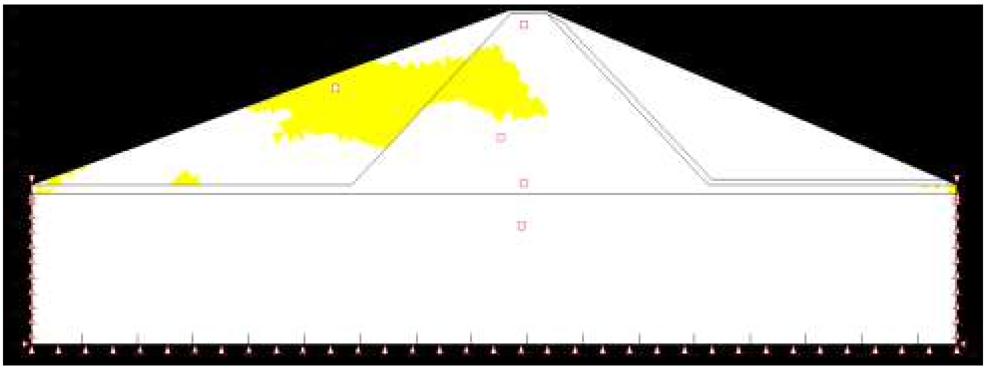


(a) X- Displacement sec.(A-A) at 0.05 g.

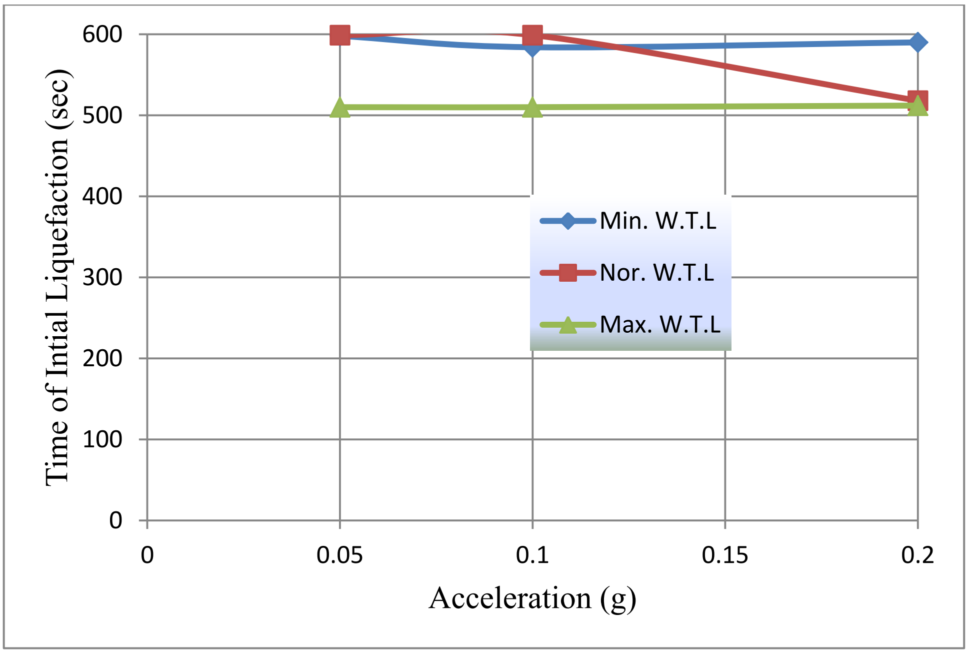


(b) X-Displacement sec.(A-A) at 0.2 g.

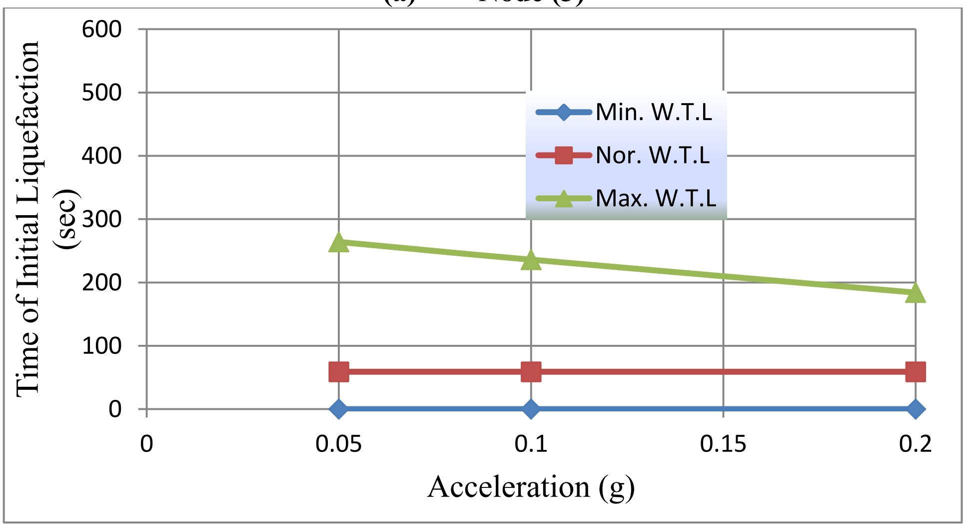
Figure (9): Earthquake response along section (A-A) through the dam at maximum water level at time 60 sec



(10): Propagation of liquefaction zones through the dam at time 600 sec under maximum horizontal acceleration of 0.2 g.

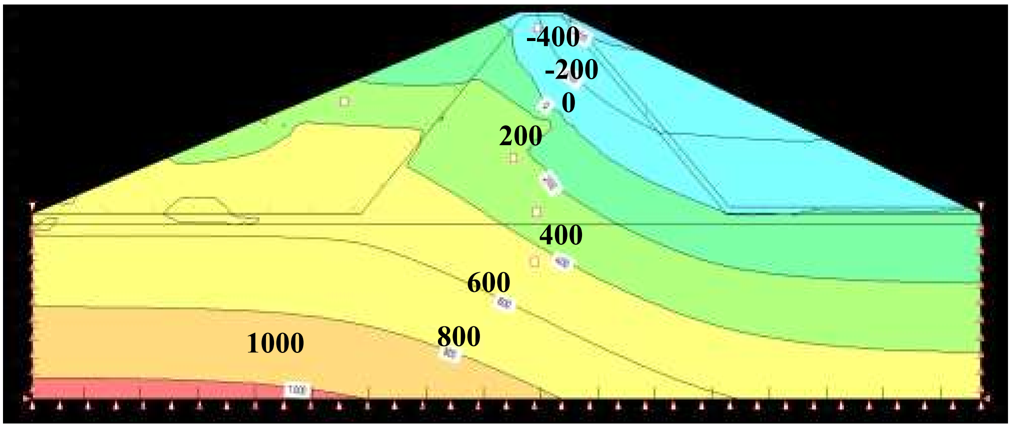


(a) Node (3)



(b) Node (5)

Figure (11): Variation of time of initial liquefaction with amplitude of acceleration at different nodes



(12) Contour lines of pore water pressure through the dam at time 600 sec under maximum horizontal acceleration of 0.2 g.

REFERENCES

[1].Center of Engineering Designs and Studies, (2007), Khassa Chai dam Planning Report.

[2].Manual User's Guide of Quake/W for Finite Element Dynamic Earthquake Analysis Program, (2004), GEO – SLOPE International. Ltd.

[3].Das, B. M., Ramana, G.V., (2011). (Principles of Soil Dynamics), Second edition, Congage Learning.

[4].Fattah, M. Y., Abbas, Nsaif, M. H., (2012), "Dynamic Response of a Zoned Earthdam to Earthquake Excitation", Engineering and Development Journal, Special issue, Proceeding of Engineering Conference of Comprehensive Research Theses, May 2012, College of Engineering Al-Mustansiriya University, Vol. 2, pp. 1052-1072.

[5].Fattah, M. Y., Omran, H. A., Hassan, M. A., (2015), " Behavior of an Earth Dam during Rapid Drawdown of Water in Reservoir – Case Study", International Journal of Advanced Research (2015), Volume 3, Issue 10, pp. 110 -122, Journal homepage: http://www.journalijar.com.

[6].Khalil. A. A., (2012). (Numerical Modeling of Pore Water Pressure Development within a Thin Clay Core in an Earth Dam), Al-Rafidain Engineering Journal, Vol. 20, No. 1, pp. 93-109.

[7].Manual User's Guide of SEEP/W for Finite Element Dynamic Earthquake Analysis Program, (2004), GEO – SLOPE International. Ltd.

[8].Nsaif, M, H., (2008) . (Coupled Dynamic Analysis of Al-Adhaim Earth Dam), M.Sc. Thesis, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.

[9].U.S. Department of the Interior Bureau of Reclamation, (2011)., Chapter 1 in (Embankment Dams General Design Standards).